such as aluminum oxide and the like. Oxygen (O_2) is adsorbed on the second region **14***b* (see FIG. **1**) of the 2D material layer **14**. For example, oxygen may be adsorbed on the 2D material layer **14**, that is, the second region **14***b* (see FIG. **1**) of the 2D material layer **14**, which is exposed through a process in which a result of FIG. **4**C is exposed to an air atmosphere, a thermal oxidation process, and/or a method of additionally supplying oxygen to the inside of the chamber.

[0072] FIGS. **5**A, **5**B, **5**C, and **5**D are graphs for describing an electrical characteristic of the diode of FIG. **1**.

[0073] First, FIG. **5**A is a graph illustrating an IV measured for the 2D material layer **14** formed of MoS before the formation of the passivation layer **18** in the diode of FIG. **1** (see FIG. **4**B). Therefore, the IV graph of FIG. **5**A illustrates a state in which oxygen is not adsorbed on any portion of the 2D material layer **14**. Referring to FIG. **5**A, the 2D material layer **14** in which oxygen is not adsorbed on any surface thereof shows a characteristic as a simple resistance device.

[0074] FIGS. **5**B and **5**C are graphs respectively illustrating an energy level and an IV measured for the 2D material layer **14** formed of MoS after the formation of the passivation layer **18** in the diode of FIG. **1** (see FIG. **4**C). That is, the graphs of FIGS. **5**B and **5**C illustrate states in which oxygen is not adsorbed on a portion of the 2D material layer **14** and is adsorbed on the other portions thereof. For example, in a state in which passivation is performed on only a portion of the 2D material layer, oxygen may be adsorbed on the other portions of the 2D material layer by exposing a 2D material layer of a device showing the characteristic of FIG. **5**A in air.

[0075] In this case, an N-type (N^{++}-type) region is induced in the portion of the 2D material layer in which passivation is performed and a P-type (N-type) region is induced in the exposed portion of the 2D material layer, and thus a characteristic of a general P-N junction diode through which a current flows only in one direction is shown (see FIGS. **5**B and **5**C). It can be seen that an ideality factor which indicates a characteristic (quality) of a diode shows 1 and a P-N junction diode having high quality is simply formed by only adsorption and separation of the oxygen.

[0076] FIG. **5**D is a graph illustrating an IV measured for a 2D material layer **14** formed of MoS when the diode of FIG. **1** is placed in a vacuum atmosphere. Therefore, the IV graph of FIG. **5**D illustrates a device restored to a state in which oxygen is not adsorbed on any portion of the surface thereof by separating the oxygen which has been adsorbed on the surface of the 2D material layer **14**. Referring to FIG. **5**D, it can be seen that the 2D material layer **14**, which is restored to the state in which the oxygen is not adsorbed on any portion of the surface thereof by separating the adsorbed oxygen, is restored to a simple resistance device. When the reversible characteristic of the diode of FIG. **1** is used, a single device (e.g., the semiconductor device of FIG. **1**) may be used as a resistance device transistor (in vacuum), or may be selectively used as the diode according to the user's purpose. Further, since an electrical characteristic of the diode is reversibly changed according to the adsorption of the oxygen, the diode is likely to be utilized also as an oxygen sensor.

[0077] FIG. **6** is a diagram illustrating a mapping of the 2D material layer **14** constituting the diode of FIG. **1** to a photocurrent. In FIG. **6**, Cr/Au and Pd denote source and drain electrodes, and Al_2O_3 denotes a passivation layer. The diagram of FIG. **6** illustrates a mapping of the 2D material layer **14** to a photocurrent generated when a laser of 487 nm focused to 1 μm is irradiated to each position of the 2D material layer **14**. Referring to FIG. **6**, it can be seen that a peak of a photocurrent is formed at an edge of the passivation layer formed of Al_2O_3 as a point at which a P-N junction is formed, that is, a position indicated by a dashed arrow. This illustration is another example illustrating a state in which a work function modulation of the 2D material layer is possible using the oxygen adsorption and separation on and from the surface of the 2D material layer formed of MoS_2. Furthermore, when the characteristic of FIG. **6** is used, a P-N junction diode having components of FIG. **1** may be used as a photodetector or a light-emitting diode (LED).

[0078] In this manner, a configuration of the P-N junction of the 2D material layer included in the diode according to the above-described exemplary embodiment, that is, a configuration of the P-N junction obtained by varying the concentration of the oxygen adsorbed on the 2D material layer, and/or a technical configuration in which a doping level may be adjusted by adjusting a concentration of the oxygen adsorbed on the surface thereof may be applied to various semiconductor devices (electronic devices) for a number of purposes. For example, the P-N junction may be applied to a diode, and also to various devices such as a solar cell, a photodetector, a transistor, a tunneling device, a memory device, a logic device, a light emitting device, an energy storage device, a display device, and the like. According to an exemplary embodiment, the transistor may have various configurations such as a field effect transistor (FET), a thin film transistor (TFT), a binary junction transistor (BJT), a barrier transistor (e.g., barristor), and the like.

[0079] In this manner, any device using a P-N junction may be applied to the 2D material layer including at least two regions having different adsorption rates of oxygen, may be applied instead of Si of an existing Si device, and may be applied to a stackable device, a flexible device, a transparent device, and the like. Since the 2D material layer is formed of a 2D material, the 2D material layer may be flexible, and since the 2D material layer has a very small thickness, the 2D material layer may have a transparent characteristic. Therefore, such a material may be usefully and advantageously applied to a stackable device, a flexible device, a transparent device, and the like.

[0080] A semiconductor device including such a 2D material layer may be a multi-layered structure. More specifically, the semiconductor device may include a semiconductor layer including a 2D material layer having two regions having different oxygen adsorption rates (in a range of 0% to 100%) on a surface thereof and at least one non-semiconductor layer provided on at least one surface of the semiconductor layer. According to an exemplary embodiment, the semiconductor layer may be formed with only the 2D material layer or another semiconductor layer may be additionally provided.

[0081] The at least one non-semiconductor layer may include at least one conductive layer and/or at least one insulating layer. The conductive layer may include a conductive 2D material layer, and the insulating layer may include an insulating 2D material layer. For example, the conductive 2D material layer may include graphene and the like, and the insulating 2D material layer may include hexagonal boron nitride (h-BN) and the like. According to